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Geology of the Northwest Pleasant Valley quadrangle Montana

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GEOLOGY OF THE NORTHWEST PLEASANT VALLEY QUADRANGLE, MONTANA

by

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ABSTRACT

The NW Pleasant Valley quadrangle is located in the Selish Mountains approximately 20 miles west of Whitefish, Montana, and covers an area of about 200 square miles. The area is underlain by an exposed thickness of 21,000 feet of Precambrian Beltian strata. The oldest rocks are in the Prichard formation, of which the upper 4,000 feet are exposed; they consist of gray and bluish-gray argillites, which are locally calcareous near the top. The Prichard grades upward into the Ravalli group, which consists mainly of quartzite and subordinate argillite, with an approximate thickness of 10,000 feet. A calcareous unit about 250 feet thick was mapped in the upper Ravalli group.

The Ravalli group grades upward into the Piegan group, which is subdivided into a lower greenish-gray, locally calcareous, argillite unit, and a middle bluish-gray limestone unit. Approximately 7,000 feet of the Piegan group are present; the upper part of this group has been eroded from the area.

The most prominent structural features are three major northwest-trending folds, ranging from 20 to 30 miles in length. The folds plunge gently to the north and south and are asymmetric, with local overturning toward the northeast. Two longitudinal faults, which are related to the folding, are believed to be high-angle thrusts dipping to the west; displacements range as high as 6,000 feet. An east-trending high-angle fault, which has left-lateral separations up to one-half mile, is interpreted as a sinistral strike-slip fault related to the folding and

thrusting. Later transverse faults appear to be near-vertical, dominantly dip-slip faults with lesser displacements. On the basis of the regional structural pattern, it is probable that at least some of the deformation is related to the Laramide orogeny.

During the late Pleistocene, the quadrangle was submerged beneath the Cordilleran ice sheet, which was at least 3,000 feet thick in parts of the area. Glacial striae indicate that the ice moved southeastward in the area. Scattered patches of glacial till, outwash, and lacustrine silt occur throughout the quadrangle.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The NW Pleasant Valley quadrangle, which covers an area of approximately 200 square miles, is located in the central part of the Selish Mountains approximately 20 miles west of Whitefish, Montana (Fig. 1). The area is a 15-minute quadrangle bounded on the west by the 115th meridan and on the north by latitude 48° 30' North. The boundaries between the Kootenai and Flathead National Forests and Lincoln and Flathead counties are located in the central part of the quadrangle.

The area is accessible via U. S. Highways #2 and #93, by way of improved light duty roads and unimproved dirt roads. County roads, Forest Service roads, and logging roads follow the major drainages and give access to much of the area. The Brush Creek road, which crosses the divide in the central part of the quadrangle, is the only road connecting the eastern and western parts of the area. Forest Service trails give access to some of the more remote parts of the quadrangle, but are not continuously maintained. The area is generally accessible only in the summer and early fall due to snow conditions.

PREVIOUS WORK

Previous work in the NW Pleasant Valley quadrangle is limited to broad reconnaissance mapping used for compilation of the State Geologic Map of Montana published in 1955. In nearby areas, Gibson (1948) mapped the Libby quadrangle, located approximately 25 miles west of the map area,

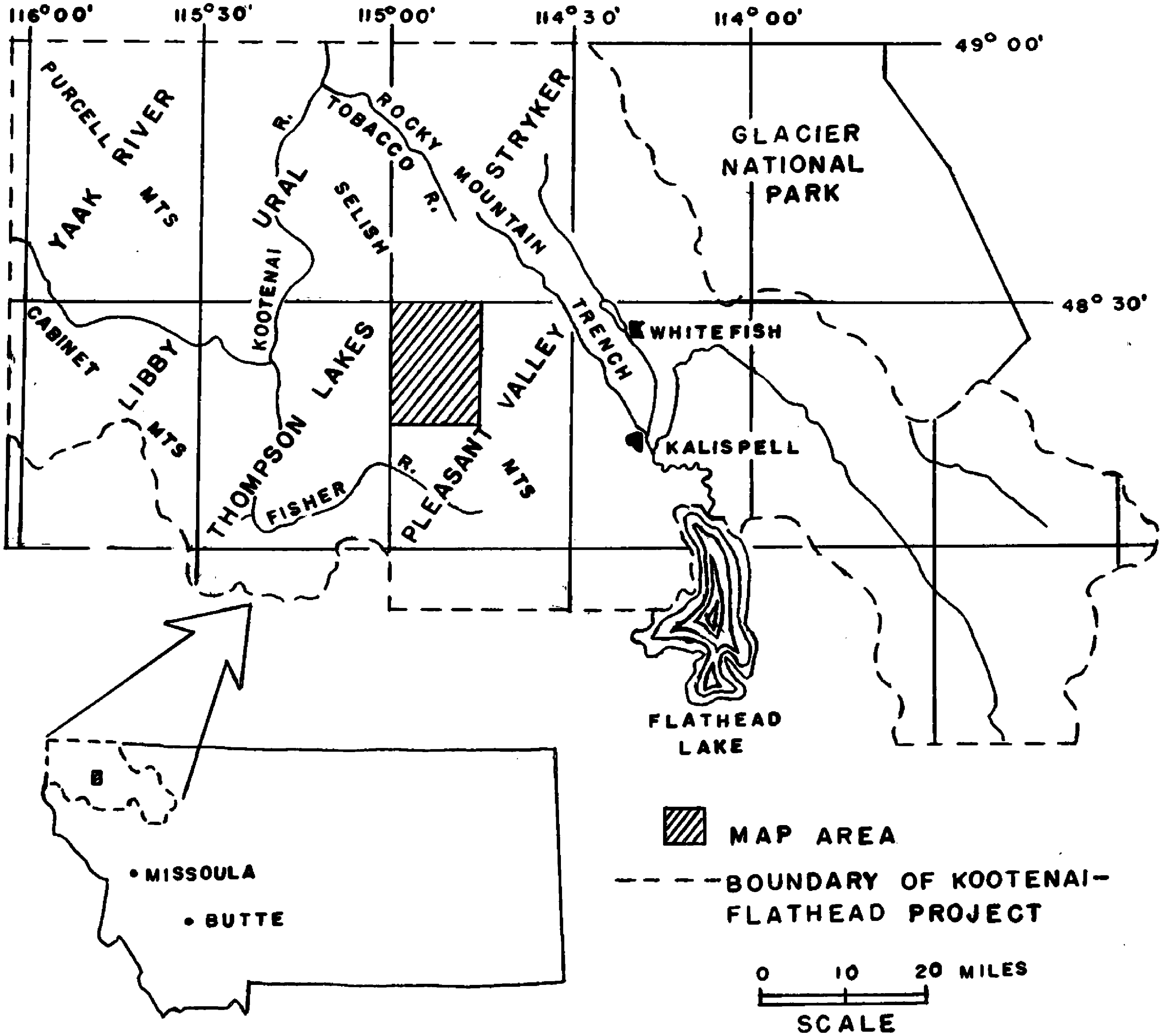

Figure 1. Index map showing area of study and other quadrangles in the Kootenai-Flathead Project area.

and described mineral deposits in that area. Alden (1953), during his studies of glaciation in western Montana, did some reconnaissance work in the vicinity of the quadrangle. Of help in understanding the regional geology was the contribution of R. A. Daly (1912), who mapped the geology at the 49th parallel from the Cascade Mountains to the Great Plains.

Since 1958 W. M. Johns and others have been engaged in a geologic reconnaissance project in the Kootenai-Flathead area of Montana, and have thus far completed geological reconnaissance surveys of the following 30-minute quadrangles: Yaak River (Johns, 1959), Thompson Lakes (Johns, 1960), Ural (Johns, 1961), and Pleasant Valley (Johns, 1962). L. P. Beer (unpublished master's thesis, University of Massachusetts) mapped the NW 15-minute Thompson Lakes quadrangle in 1959. D. Sommers (unpublished master's thesis, University of Rochester) and A. Sheldon (unpublished master's thesis, Montana State College) mapped the NE and NW 15-minute Ural quadrangles respectively in 1960. F. V. Latuszynski (Montana State University) mapped the SW 15-minute Pleasant Valley quadrangle in 1961.

PRESENT STUDY

The investigation was carried out under the direction of the Montana Bureau of Mines and Geology as part of a five-year project (June 1958 to June 1963) sponsored by the Pacific Power and Light Company and the Great Northern Railway Company. The purpose of the project is to make a geologic reconnaissance of the Kootenai-Flathead area in northwestern Montana (Fig. 1) to ascertain the potential mineral resources of the area.

Approximately 65 days were spent in the field between June and October of 1961, and four additional days were spent in the field in the Spring of 1962. Automobile traverses and traverses on foot were utilized to determine the geology of the quadrangle. Saddle and pack horses served as a means of transportation during the mapping of the remote southeastern part of the quadrangle.

Where possible, traverses were made perpendicular to the regional strike in the proximity of ridge crests, where vegetation and soil cover are sparse. Spacing of traverses was on the order of two or three miles; faults, contacts, and key units were projected from traverse to traverse.

1:20,000 scale U. S. Department of Agriculture Commodity Stabilization Service aerial photographs flown in 1954 and 1955 aided in planning, locating, interpreting, and plotting data. The geology was plotted on a U. S. Forest Service planimetric map at a scale of one-half mile to the inch. An Army Map Service sheet (Kalispell, Montana, 1:250,000 series) was used for topographic control in making cross sections and establishing elevations in the quadrangle. The geologic map and cross sections were later reduced to a scale of one mile to the inch for inclusion in this report.

ACKNOWLEDGEMENTS

The writer is grateful to the Montana Bureau of Mines and Geology for financial support and for permission to use the data collected while in their employ. Special thanks are due Dr. Robert M. Weidman and the other faculty members of the Geology Department of Montana State University for their assistance and cooperation. Helpful discussions with Willis M. Johns of the Montana Bureau of Mines and Geology, and with Tom Ward, Dick Galster and Ralph Morrison of the Army Corps of Engineers are greatly appreciated.

PHYSIOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Selish Mountains (Fig. 1), previously called the Flathead Mountains, are located in the Northern Rocky Mountain Physiographic Province (Fenneman, 1931), and trend in a north to northwest direction typical of most other ranges in northwestern Montana. This range extends southeast from the Tobacco River for approximately 80 miles to where it terminates southwest of Flathead Lake. It is bounded on the west by the Kootenai River and on the east by the Rocky Mountain Trench, a remarkably continuous and regular topographic depression first described by Daly (1912, p. 26). The trench extends from the Laird River in Canada southeast for approximately 800 miles to near the head of Flathead Lake in Montana.

Elk Divide, the prominent north-trending ridge in the central part of the quadrange, acts as a pronounced drainage divide, and is the locus of the higher peaks in the map area (Fig. 2, Plate 1). Most of the peaks range between elevations of 5,000 and 6,500 feet, and the highest peak in the quadrangle has an elevation of 6,581 feet. The lowest elevation, 3,200 feet, is located where Little Wolf Creek and Wolf Creek leave the quadrangle on the west. Local relief in the area is approximately 2,500 feet.

The Selish Mountains exhibit a mature topography that is primarily the result of pre-glacial stream erosion which dissected a broad mountain range formed during the Laramide orogeny. The major valleys in the

Figure 2. View looking northeast in the map area. Elk Mountain (elevation 6,581 feet) is just left of center, on the crest of Elk Divide. Note rounded topography and thick stands of timber.

quadrangle are approximately a quarter to a half-mile wide and are characterized by moderate gradients averaging 50 to 60 feet per mile. Gradients increase markedly in the higher and narrower tributaries, and may reach 600 to 800 feet per mile.

Drainage in the quadrangle is in two major directions (Fig. 3 and Plate 1). Wolf Creek and Little Wolf Creek, the major drainages on the west side of Elk Divide, flow westward into the Fisher River, which drains northward into the Kootnai River. Good Creek, Sheppard Creek, and Griffin Creek, the major drainages on the east side of the divide, flow eastward into the Stillwater River, which flows southward into the Flathead River near the head of Flathead Lake.

Major streams in the western part of the quadrangle have cut down approximately 1,000 feet deeper than those in the eastern part, causing the eastern half of the quadrangle to stand like a plateau compared to the western half. This phenomenon is probably the result of greater downcutting by the Kootenai River to the west than the rivers in the Rocky Mountain Trench to the east, because of the considerably greater distance that the water east of the divide must flow before reaching a common destination in the Columbia River.

The drainage pattern in the quadrangle is generally dendritic, but local examples of structurally controlled drainage are present. The upper part of Wolf Creek trends in a southeast direction following the strike of the beds close to the contact between the Prichard formation and the Ravalli group (Plate 1). This control was apparently produced by the differential resistance of beds where the softer rocks of the Prichard formation grade upward into more resistant Ravalli rocks. Faulting has probably exerted an influence on the position of Dunsire Creek, and Plume Creek appears to be controlled in its upper and lower parts by faulting and bedding respectively (Plate 1). In other parts of the area the differential hardness of beds and faulting apparently control the direction of several unnamed tributaries, at least for short distances.

CLIMATE AND VEGETATION

The climate in the map area is characteristic of the Northern Rocky Mountain Physiographic Province, with abundant annual precipitation and large diurnal and seasonal variations in temperature. Temperature and precipitation in the quadrangle are similar to those at Kalispell, Montana, located 20 miles to the southeast, although precipitation is probably greater in the mountains than in the Flathead Valley. The U. S. Weather Bureau at Kalispell reports that the mean annual precipitation in the Kalispell area for the period between 1921 to 1950 was 16.38 inches. For a 30-year period the mean annual temperature was 43.2°F. The lowest temperature recorded in the last 40 years was -38°F. in 1950, and the highest was 104°F. in 1960. During an eleven year period, seasonal snowfall averaged 68.3 inches.

With the exception of ridge-crests and steeper valley walls, the mountains in the quadrangle are covered with a veneer of glacial till, which has undergone weathering to form a fertile soil. Abundant precipitation has fostered the growth of dense stands of timber, consisting dominantly of pine, larch, and fir (Fig. 2). An interesting feature is the occurrence of the world's largest living larch tree (*Larix occidentalis*) just south of the Old Railroad Grade (Plate 1) approximately one mile west of the boundary within the NE Thompson Lakes quadrangle.

GLACIATION

Evidence of Pleistocene glaciation occurs throughout the NW Pleasant Valley quadrangle. During the Wisconsin and earlier stages of glaciation, a great tongue of the Cordilleran ice invaded the Rocky Mountain Trench from Canada (Alden, 1953, p. 115). In its most recent advance this great mass of ice, designated the Flathead Glacier, extended south as far as Polson, located on the south side of Flathead Lake (Fig. 1). The advancing western part of the ice mass diverged from the Rocky Mountain Trench at the north end of the Selish Mountains (Fig. 1) and moved down the Kootenai River valley (Alden, 1953, p. 134). This ice lobe, designated the East Kootenai Glacier by Alden, extended up the valley of Fisher River for 25 miles south of the junction of the Fisher River with the Kootenai River at Jennings, Montana (Alden, 1953, p. 134).

The elevations at which glacial striations, polishing, and grooving have been found indicate that the highest peaks and ridges of the Selish Mountains in the map area were wholly submerged beneath the Cordilleran ice. This indicates that the ice was at least 3,000 feet thick near the western border of the quadrangle along Wolf Creek and Little Wolf Creek (Fig. 3, Plate 1); westward, in the Kootenai River valley, the ice was probably at least 4,400 feet deep. In the Rocky Mountain Trench to the east the ice was probably at least 3,600 feet thick. These estimates of the ice thicknesses are based on the assumption that no uplift has occurred in the region since Pleistocene time.

Submergence by the moving ice profoundly affected the landscape in the quadrangle, producing rounded topography and softened contours at many places (Fig. 2). Glacial erratics occur on many of the ridges in the map area.

Bearings of glacial striations indicate that the ice moved in a general south-southeast direction in the quadrangle (Fig. 3). In the vicinity of Sanders Mountain, the striations bear west-southwest, and occur in saddles through Elk Divide. There the striations apparently reflect a local southwestward movement of ice into the drainage of Little Wolf Creek while the main ice mass moved southeastward in the area. In the Thompson Lakes and Ural quadrangles to the west and northwest (Fig.1), glacial striations trend in a general southwest direction (Johns, 1961). This change in the bearings of striations from a southeast to a southwest direction occurs near the northwest corner of the NW Pleasant Valley quadrangle, which is the area of divergence of the East Kootenai Glacier from the Flathead Glacier. The southeast-trending part of Wolf Creek (Fig. 3, Plate 1) flows through a distinctly U-shaped, glacially modified valley, which may have directed the ice movement in a southeast direction in conjunction with the main southeast axial flow of the Flathead Glacier in the Rocky Mountain Trench to the east. West of Wolf Creek in the Thompson Lakes quadrangle, the southwest-trending striations apparently reflect the main axial flow of the East Kootenai Glacier.

Scattered occurrences of glacial drift, including coarse gravels, till, and silt are present throughout the quadrangle, and were grouped together with Recent alluvium as Qg (Quaternary glacial deposits, Plate 1) in the reconnaissance mapping. Glacial till floors much of the valley bottom of upper Wolf Creek and the lower part of Brush Creek (Plate 1). Exposures of buff-colored, laminated lacustrine silt occur intermittently in the lower part of the valley of Little Wolf Creek (Plate 1, Fig. 3) in the quadrangle, and along Wolf Creek in the Thompson Lakes quadrangle, just north of the junction with Little Wolf Creek. These silts may have been deposited in an arm of Glacial Lake Kootenai, a proglacial lake formed when ice of the Wisconsin stage of glaciation began receding northward and the valley of the Kootenai River to the west was still blocked by ice (Alden, 1953, p. 135).

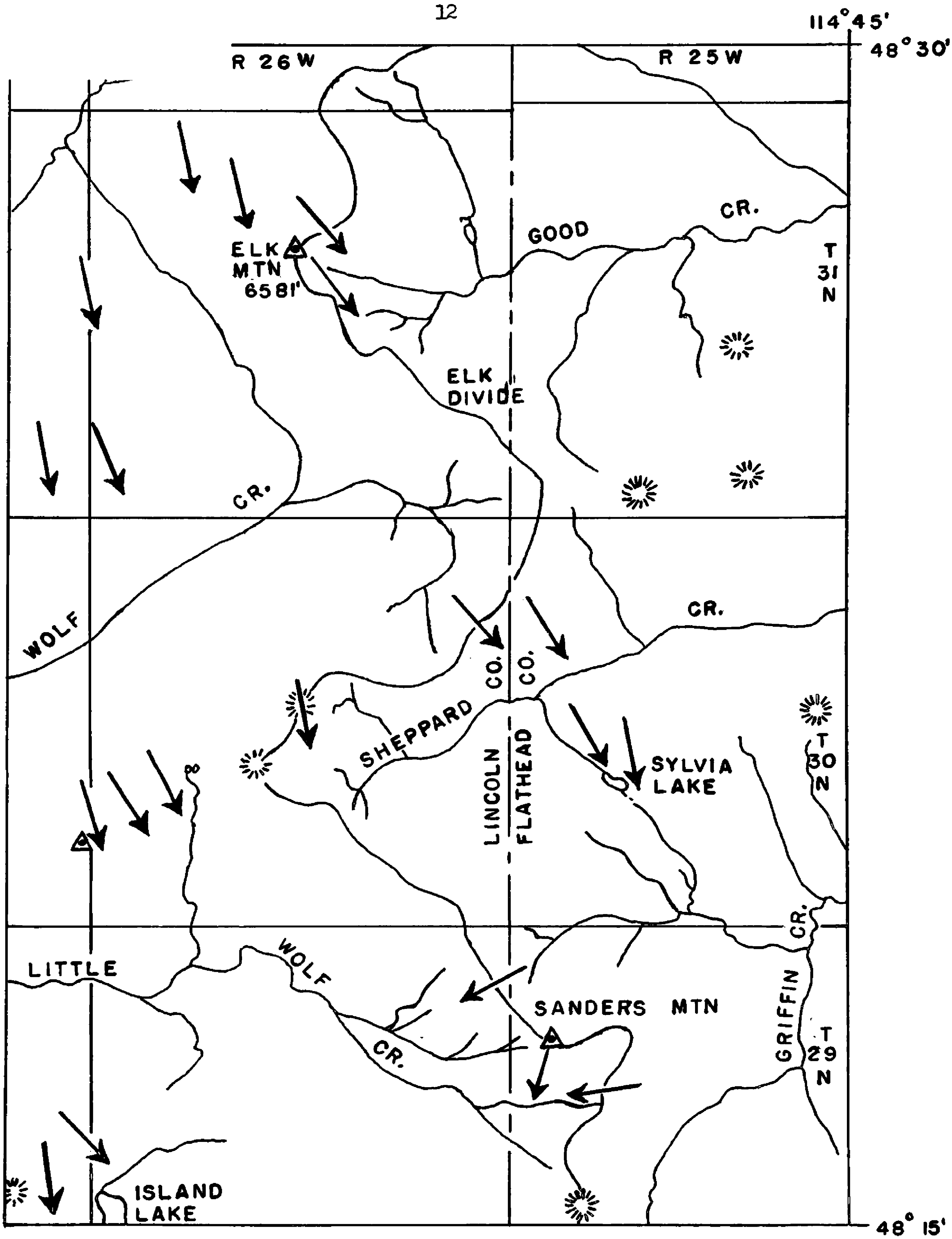

Figure 3. Map showing bearings of glacial striae and direction of movement of the Cordilleran ice sheet in the map area.

Sylvia Lake (Fig. 3, Plate 1), at an elevation of approximately 5,000 feet, is held up by a morainal dam at the south end. The surface of the moraine is pitted with small kettle holes formed by the melting of buried masses of glacial ice. The morainal material was probably deposited by a southeast-trending tongue of ice during the last recessional phase of the Cordilleran ice sheet. This ice tongue apparently flowed southeastward through the saddle of Brush Pass (Fig. 3, Plate 1), and may have been an extension of ice which occupied the valley of Wolf Creek.

South of Sylvia Lake, on the north side of the Hand Creek road (Plate 1), good exposures of buff-colored, laminated lacustrine sandy silt, at least fifteen feet thick, occur at an elevation of 4,800 to 5,000 feet. (Fig. 4). It is possible that these silts were deposited in a small

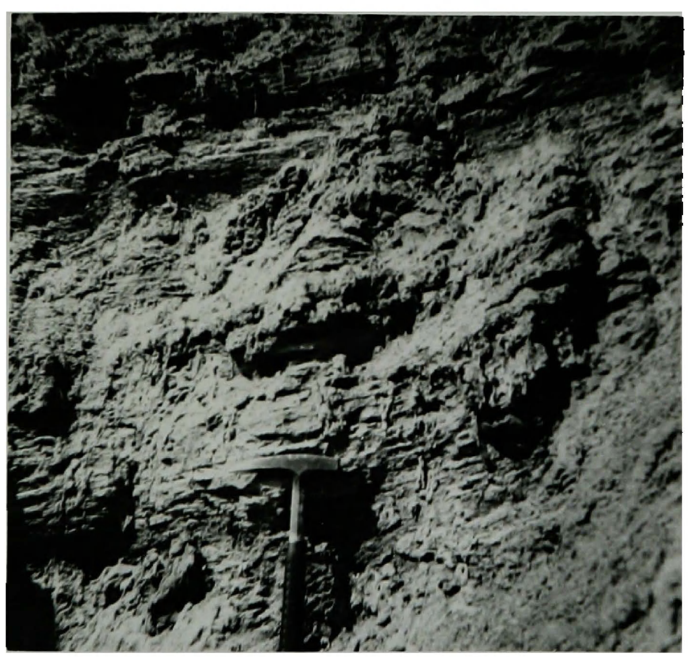

Figure 4. Laminated lacustrine sandy silts exposed south of Sylvia Lake along the north side of Hand Creek road at an elevation of 4,800 to 5,000 feet.

proglacial lake ponded by the ice and morainal debris in the valley of Sylvia Lake and by ice blockage in Griffin Creek. A small rocky gorge (elevation between 4,800 and 5,000 feet), located at the head of Little Wolf Creek in a notch through Elk Divide (Plate 1), extends in a westward direction and may have acted as a spillway for the small proglacial lake.

Island Lake (Fig. 3, Plate 1), at an elevation of approximately 3,500 feet, is impounded by a morainal dam at the south end (Alden, 1953, p. 136). The morainal debris which bounds the lake was probably deposited by a receding tongue of ice that extended northwestward into the valley of Wolf Creek in the Thompson Lakes quadrangle.

STRATIGRAPHY

GEOLOGIC SETTING

Most of the mountainous region of northwestern Montana is underlain by an extremely thick sequence of strata which belong to the Belt series of Precambrian age. Post-Beltian sediments have been removed by erosion, except where Paleozoic sediments have been preserved by consequence of faulting, and the argillites, quartzites, and carbonates of the Belt series make up the dominant lithology. Tertiary basin-fill sediments are exposed intermittently; Pleistocene glacial features and drift are conspicuous throughout the region. Scattered occurrences of Precambrian intrusives and extrusives, and some late Mesozoic or early Cenozoic intrusives are present in the region, but none were found in the area of study.

The Belt sediments in the region have been buckled into broad to relatively tight north to northwest-trending folds. Longitudinal faults, consisting of both thrusts and normal faults, are prominent structural features. Transverse faults are present, and commonly displace northwest-trending structures. The bulk of the diastrophism is generally considered, by most geologists, to be related to the Laramide orogeny of late Cretaceous or early Tertiary time.

THE BELT SERIES (PRECAMBRIAN)

In general, the Beltian environment was that of a shallow, discontinuous sea which occupied the extensive, slowly sudsiding Rocky Mountain geosyncline during late Precambrian time. The Belt sediments accumulated to a great thickness, particularly in the axial portion of the geosyncline; approximately 40,000 feet are exposed in the Libby quadrangle (Gibson, 1948, p. 8) with an unknown thickness concealed at the base and removed by erosion at the top. The sediments were probably derived from a landmass to the west, and land changes, probably general uplift, apparently influenced sedimentation (Fenton and Fenton, 1937b, p. 1940). Sometimes abundant clastics were supplied, which silted up the basins, after which diminutions permitted the deposition of carbonates (Fenton and Fenton, 1937b, p. 1940). Shallow water features, such as sun cracks, mud chips, and raindrop imprints are common in the strata. Stromatolites, or fossil algae, are widespread in the Belt series, and are the only definite life forms known to have existed during Beltian time.

In northwestern Montana, the Belt series can be divided into three major groups; in ascending order these are the Ravalli, Piegan, and Missoula groups. This division follows the work of Ross (1959a). Ultimately the Belt rocks which underlie the Ravalli group may be given group rank (Ross, 1959a, p. 6).

The NW Pleasant Valley quadrangle is underlain by an exposed thickness of approximately 21,000 feet of Beltian strata. Rocks of only the Piegan group, the Ravalli group, and the Prichard formation (pre-Ravalli rocks) are present (Table I). The base of the Prichard formation is not exposed in the map area, and the upper part of the Piegan group and the overlying Missoula group have been removed by erosion. Boundaries between the rock units are gradational.

Table I. Generalized Stratigraphic Section of Precambrian Belt Strata in the Map Area.

DIVISION	GENERAL LITHOLOGY	THICKNESS (feet)
	Top eroded	
PIEGAN GROUP	Bluish to dark-gray silty limestone and dolomite unit. Molar tooth structure. Weathers brown and orange. 3,500 ± feet exposed. Greenish-gray calcareous and siliceous argillite unit. 3,500 ± feet thick	7,000 ±
RAVALLI GROUP	Light-gray, cross-stratified quartzite, and purplish-gray argillite. Calcareous argillite and limestone unit 250 to 500 feet thick located about 2,500 feet below Piegan-Ravalli contact. 4,000 ± feet thick. Medium to very light-gray quartzite and argillite. Sun cracks, octahedral magnetite, and biotite porphyroblasts. 4,000 ± feet thick. Greenish to medium-gray quartzite and argillite. Biotite porphyroblasts. Weathers pale greenish-gray. 2,000 ± feet thick	10,000 ±
PRICHARD FORMATION	Gray to bluish-gray argillite, becoming silty toward top. Generally calcareous toward top. Biotite porphyroblasts and sericite abundant. Weathers typically reddish-brown	4,000 ±
	Base concealed	

The Belt sediments in the map area have been subjected to a relatively low-grade regional metamorphism that has converted the original sandstones, mudstones, and limy shales to quartzites and argillites. The rocks exhibit features indicative of metamorphism of a low-grade subfacies of the greenschist facies. However, most of the original sedimentary characteristics have been preserved. In the quadrangle, the Prichard formation is composed dominantly of argillite, and the Ravalli group consists mainly of quartzite with subordinate argillite. Calcareous rocks, which are commonly silty and argillaceous, comprise the dominant lithology of the Piegan group.

In many parts of the map area, the terrain is covered by glacial drift, soil, and timber (Fig. 2), and as a result outcrops of the Belt section are relatively infrequent and rarely continue for appreciable distances. This condition, combined with structural complexities, resulted in a fragmentary accumulation of lithologic information. However, the lithologic descriptions are believed to be representative. Thicknesses of rock units were obtained mainly by scaling from the geologic map and cross sections. The Geological Society of America Rock Color Chart (Goddard, 1951) was of great value in standardizing rock colors in the field. Terminology used in describing the stratification of the rock units is based on the practical suggestion of McKee and Weir (1953), and is presented in Table II.

Table II. Quantitative Terms Used In Describing Layered Rocks. After McKee and Weir (1953)

Stratitication	Thickness	Splitting property
Very thick-bedded	Greater than 120 cm. (about 4 ft.)	Massive
Thick-bedded	120 cm. (about 4 ft.) to 60 cm.	Blocky
Thin-bedded	60 cm. (about 2 ft.) to 5 cm.	Slabby
Very thin-bedded	5 cm. (about 2 in.) to 1 cm.	Flaggy
Laminated	1 cm. (about ½ in.) to 2 mm.	Shaly (claystone, siltstone)
		Platy (sandstone, limestone)
Thinly laminated	2 mm. (about .08 in.) or less	Papery

<u>Prichard formation</u>: The oldest exposed rocks in the NW Pleasant Valley quadrangle belong to the Prichard formation. Originally named for exposures in the Prichard Creek drainage basin of the Coeur d'Alene area in northern Idaho (Ransome, 1905, p. 281), the Prichard was correlated eastward as far as Dixon, Montana, and into parts of the Cabinet and Purcell Mountains (Calkins, 1909, pp. 35-37). The mapping was continued into the Trout Creek and Libby quadrangle (Gibson, Jenks, and Campbell, 1941, pp. 365-367), and Johns(1959, 1960, 1961) carried the correlation into the quadrangles of the Kootenai-Flathead project (Fig. 1).

In the NW Pleasant Valley quadrangle, approximately 4,000 feet of the upper part of the Prichard formation are exposed. The greatest thickness of Prichard strata occurs in the southwest part of the quadrangle in the vicinity of Island Lake, where the formation crops out on the west limb of the Wolf Creek syncline. Prichard rocks are also exposed along Wolf Creek, Little Wolf Creek, and at intervals on the west (upthrown) side of the Brush Pass thrust (Plate 1).

The Prichard formation is a relatively homogeneous sequence of strata consisting dominantly of gray and bluish-gray argillites, which become more quartzitic toward the top. Some interbeds of fine-grained quartzites and argillaceous quartzites occur intermittently throughout the sequence. Prichard strata are generally very thin to thin-bedded, and commonly exhibit a shaly to flaggy appearance. Sun cracks were noted near the top of the formation. Joint and bedding surfaces of the Prichard strata characteristically weather to a reddish-brown color, probably as a result of the oxidation of the iron sulfides present in the rock (Fig. 5).

Figure 5. Strata of the Prichard formation, located about one mile north of Island Lake, along the Old Railroad Grade. Note typical reddish-brown weathering, and flaggy to shaly nature. East-trending joints are most prominent.

Strata of the Prichard formation are commonly laminated in tones of gray, particularly in the upper part of the formation (Fig. 6). In thin section, these laminae are seen to be the result of quartzitic layers interlaminated with argillite layers. Thin black laminae are sometimes evident and apparently are composed of carbonaceous material concentrated in layers. The more quartzitic layers are composed of grains generally less than 0.03 mm. in diameter, but which sometimes range as great as 0.10 mm. The quartz grains are strongly recrystallized, and

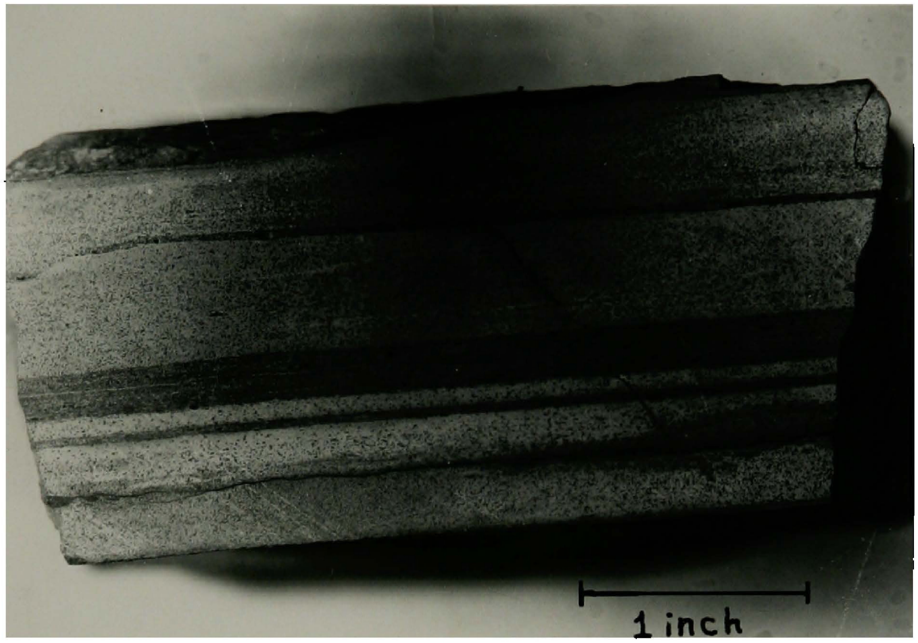

Figure 6. Lamination in the Prichard formation. Minute dark specks which give the "salt and pepper" appearance are porphyroblasts of biotite. Sample taken from upper part of the formation near the western boundary of the area, just north of the Wolf Creek-Trego road.

exhibit welded boundaries. Sodic plagioclase makes up two percent or less of the sections.

Randomly oriented porphyroblasts of chloritoid, up to 1.85 mm. in diameter, are present in one of the thin sections (appendix, section #1) and contain inclusions of quartz, zircon, and magnetite. Porphyroblasts of biotite, up to 0.4 mm. in diameter, are common in all the sections. The biotite metacrysts are poikilitic, containing inclusions of quartz, zircon, and magnetite. Sericite is abundant in all the sections, and minor amounts of chlorite occur as minute flakes. The above mineralogic assemblage indicates that the Prichard formation has been regionally metamorphosed to a quartz-albite-epidote-biotite subfacies of the greenschist facies (Turner and Verhoogen, 1960, pp. 534-536). Minor amounts of fine-grained, detrital zircon, apatite, and rutile are also present in the sections. Magnetite, occurring as granules and strings of small octahedra, is disseminated through the rock, and makes up from one to two percent of the sections. In some places, the magnetite is seen to completely enclose the quartz grains. The magnetite most probably was recrystallized from detrital or diagenetic iron-bearing minerals during the regional metamorphism.

Near the top of the formation, the Prichard was found to be locally calcareous, containing minor interbeds of dark to medium-gray calcareous argillite and limestone, usually somewhat silty. These calcareous interbeds were found in a zone approximately 500 feet thick just below the top of the formation, but constitute only a minor portion of the whole sequence of beds in the zone. A distinctive calcareous unit was found at the top of the Prichard formation in several places throughout the area; exposures of the unit up to eight feet thick are present (Fig. 7). It could not be determined how far this unit persists laterally, because of the discontinuity of outcrops. F. Latuszynski (personal communication) recognizes a similar unit in the SW Pleasant Valley quadrangle.

The carbonate unit is dominantly a medium-gray in color, and exhibits white to light-gray laminae. In thin section, it is composed predominantly of very fine-grained quartz in a clay matrix. Calcite occurs in oval-shaped clusters and bands of crystals (up to 0.4 mm.) considerably larger than the grains of the rest of the rock, and sometimes as a cement between detrital grains. Porphyroblasts of biotite

Figure 7. Calcareous unit at the top of the Prichard formation, approximately eight feet thick. Note the coarse and pitted weathered surface, apparently produced by weathering out clusters and laminae of calcite. Exposed about one mile west-northwest of Elk Mountain on the west-dipping limb of the Elk Mountain anticline.

up to 0.25 mm. in diameter are abundant, and are often concentrated in thin laminae. The unit weathers to a characteristic coarse and pitted surface, probably as a result of the weathering out of the clusters and laminae of calcite. The unit usually weathers light-gray, but some exposures exhibit a reddish-brown surface, particularly where blebs of disseminated pyrite are evident.

Other workers in the Kootenai-Flathead area of Montana have also found the Prichard formation to be locally calcareous. In the Libby and Trout Creek quadrangles, some beds of the Prichard are somewhat calcareous (Gibson, Jenks, and Campbell, 1941, p. 368). Johns (1960, p. 8) found calcite-bearing beds in the upper part of the Prichard in the Thompson Lakes quadrangle, but did not believe they were extensive. Sheldon (1961, p. 31) recognized the calcareous nature of the top of the Prichard in the NW Ural quadrangle to the northwest, and believed that the upper Prichard may be a more clastic facies of the Altyn limestone in Glacier National Park some 40 to 50 miles east of the area of study. Ross (1959a, pp. 13-14) mentions the possibility that the Altyn limestone may be stratigraphically equivalent to pre-Ravalli rocks, possibly to some part of the Prichard formation. Persistence of the calcareous zone at the top of the Prichard formation into the Pleasant Valley quadrangle, which is further east than the Libby, Ural, and Thompson Lakes quadrangles, lends support to the theory that the upper Prichard may be a more clastic facies of the Altyn, especially since the calcareous zone appears to be thicker and more limy in the Pleasant Valley quadrangle. However, this apparent increase in thickness and lime content is inferred from the previous published descriptions, and more detailed work should be undertaken on this interesting problem.

The top of the distinctive calcareous unit described above served as a convenient boundary between the Prichard formation and the overlying Ravalli group where it was encountered in the quadrangle. Approximately one mile northwest of Elk Mountain, for example, the calcareous unit grades upward into dominantly gray and greenish-gray quartzites and argillites of the lower Ravalli group through a transitional zone approximately 200 feet thick. Similar lithologic conditions were found just south of Sanders Mountain, west of Sylvia Lake, and in the vicinity of Horse Hill (Plate 1). East of Island Lake, however, the contact is gradational over a distance of approximately 500 feet. There the contact was placed between the last laminated, reddish-brown weathering quartzitic argillites of the Prichard formation and the first good gray and greenish-gray quartzites of the lower Ravalli group; the calcareous marker unit was not found in that area, probably because of concealment by overburden.

Ravalli group: The Ravalli group consists of that dominantly quartzitic sequence of strata above the Prichard formation and below the Piegan group in the quadrangle. Walcott (1906, p. 7) used the term Ravalli when he divided the Belt rocks near Ravalli, Montana, into the Ravalli, Blackfoot, and Camp Creek "series", which essentially correspond to the present Ravalli, Piegan, and Missoula groups, respectively. Calkins (1909, pp. 37-41) applied the term Ravalli group to encompass the Burke formation, the Revett quartzite, and the St. Regis formation where their boundaries become indistinct in the Cabinet Range of northwestern Montana (Fig. 1), because he believed they were equivalent to Walcott's Ravalli series. Gibson, et al. (1941, pp. 365-368) continued the mapping in the Libby and Trout Creek quadrangles, and Johns (1959, 1960, 1961) carried the correlation into the other quadrangles of the Kootenai-Flathead project area (Fig. 1).

To the east, in and near Glacier National Park (Fig. 1), the Ravalli group presently includes the Altyn limestone, and the Appekunny and Grinnell formations (Clapp and Deiss, 1931, Fenton and Fenton, 1937b). The questionable inclusion of the Altyn limestone in the Ravalli group has been discussed under the Prichard formation.

This group is extensive in the map area, and because of its resistant character forms bold, massive ledges and prominent talus slopes (Fig. 8).

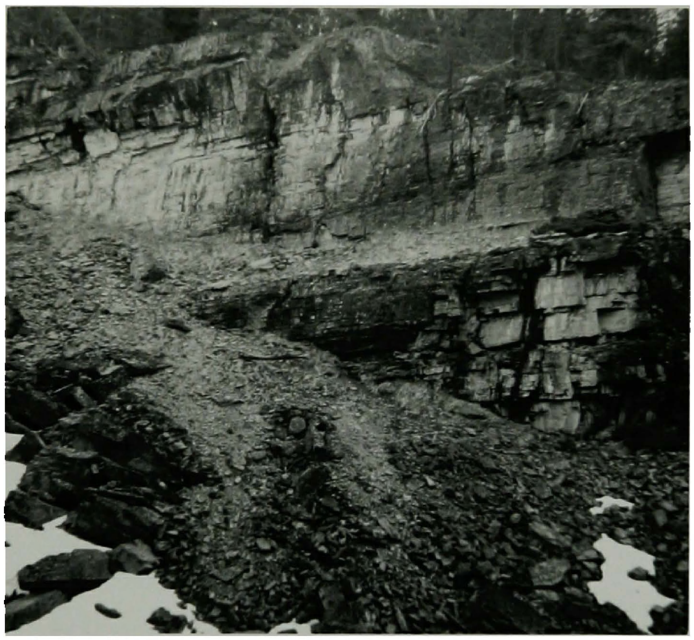

Figure 8. Ledges and talus formed by gently-dipping strata of the lower Ravalli group. Exposed about one mile northwest of Elk Mountain.

Rocks of the Ravalli group occupy the trough of the Wolf Creek syncline in the western part of the quadrangle, except where streams have cut down and exposed the underlying Prichard formation. The group crops out extensively on the east limb of the Elk Mountain anticline in a zone extending from the northeast corner to the southeast corner of the quadrangle (Plate 1). Resistance to erosion of the Ravalli group is demonstrated by the fact that the rocks hold up Elk Divide throughout most of the quadrangle.

The Ravalli group is approximately 10,000 feet thick in the quadrangle, although a continuous section is not present because of structural complexities and removal by erosion. This compares with the following approximate thicknesses in adjacent areas: 11,000 feet in the Thompson Lakes quadrangle to the west (Johns, 1960); 10,000 feet in the SW Pleasant Valley quadrangle to the south (F. Latuszynski, personal communication); and 10,000 feet thick in the SE Pleasant Valley quadrangle (Johns, personal communication).

In the map area, the Ravalli group is dominantly quartzitic throughout; however, lithologies range from quartzites to argillites. Sun cracks and ripple marks occur throughout the sequence. Although the Ravalli group was not subdivided in the quadrangle, three general lithologic zones seem to be distinguishable and might hold up as mapping units for future workers.

The lower Ravalli is comprised mainly of greenish-gray and medium-gray, very thin to thick-bedded quartzites and argillites, which contain some ripple marks and sun cracks. Porphyroblasts of biotite are present, and often are concentrated in thin laminae. The quartzites are generally fine-grained, and sericite is common throughout the sequence. Lower Ravalli rocks commonly weather to a pale greenish-gray surface, and are approximately 2,000 feet thick in the quadrangle.

This lower zone grades upward into the middle Ravalli rocks which consist dominantly of fine-grained, light to very light-gray, thin to thick-bedded quartzites, which commonly present a blocky to massive appearance. Interbedded with the quartzites of the middle Ravalli are some units of medium-gray argillite and quartzitic argillite, which commonly exhibit well-developed sun cracks, plus occasional thin interbeds of greenish-gray argillite. The strata are sometimes laminated in gray tones, and porphyroblasts of biotite are abundant in some of the rocks. Some ripple-marked beds were noted in the sequence. Magnetite, often occurring as perfect octahedra, is abundant. The middle Ravalli is approximately 4,000 feet thick.

In thin section, a quartzite from the middle Ravalli consists mainly of quartz grains generally less than 0.1 mm. in diameter. The grains have strongly welded boundaries, and apparently have been recrystallized. Sericite is present in varying amounts, as well as a small amount (less than five percent) of sodic plagioclase. Magnetite makes up about two to three percent of the section, and occurs as granules and octahedra. Inclusions of quartz are present in some of the granules. The magnetite may have been recrystallized from detrital or diagenetic iron-bearing minerals during metamorphism.

The middle zone grades into the upper Ravalli which consists of approximately 4,000 feet of fine-grained, medium to light-gray to white, thin to thick-bedded quartzites which characteristically display thin, purple laminae, cross-stratification, channeling, and ripple marks. Some quartzite beds of the upper Ravalli exhibit "hieroglyphic" structure (Johns, personal commincation), a term used to designate the cuneiform pattern produced where the laminae become extremely distorted and irregular. Interbedded with the quartzites are some light to medium-gray, purple-toned, laminated to very thin-bedded argillites which contain sun cracks and mud chips.

In thin section, a quartzite from the upper Ravalli consists of recrystallized quartz grains from 0.1 to 0.15 mm. in diameter, and which are characterized by welded and sutured boundaries. Sodic plagioclase makes up about ten percent of the section. Sericite is abundant, and a few porphyroblasts of biotite up to 0.2 mm. in diameter are present. The features displayed by the Ravalli rocks are indicative of the quartz-albite-epidote-biotite subfacies of the greenschist facies (Turner and Verhoogen, 1960, pp. 534-536).

A sequence of calcareous argillite and limestone beds approximately 250 to 500 feet thick occurs in the upper Ravalli approximately 2,500 feet below the Ravalli-Piegan contact (Fig. 9, Plate 1). This calcareous unit, which apparently dies out to the northwest in the quadrangle, is medium-gray in color, very thin to thin-bedded, and commonly displays a strongly developed cleavage. The unit persists southeastward into the NE and SE Pleasant Valley quadrangles for approximately ten miles (Johns, 1962).

In the upper 300 feet of the Ravalli group, white quartzite beds, up to eight inches thick, occur consistently in light-gray to purplish-gray quartzite and argillite. In thin section the white quartzite consists mainly of medium-grained quartz (0.3 to 0.4 mm. in diameter), which exhibits secondary quartz overgrowths and welded grain boundaries. Random grains of sodic plagioclase make up about five percent of the section.

The contact between the Ravalli group and the overlying Piegan group is gradational over 100 to 200 feet, and was placed just above the last cross-stratified, light-gray to white quartzites of the Ravalli group. Here greenish to purplish-gray calcareous argillites and

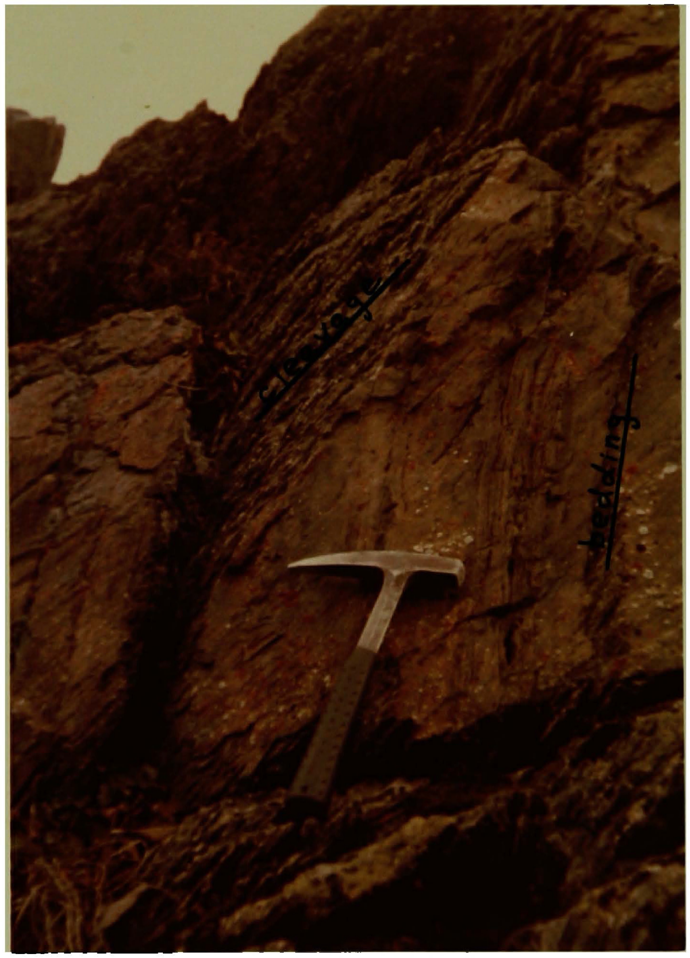

Figure 9. Calcareous argillite and impure limestone unit of the upper Ravalli group, exposed northeast of Sylvia Lake. Bedding strikes N 20°W, dips 80°W, and is overturned to the NE. Note fracture cleavage, which strikes N 10°W, dips 65°W.

argillites of the basal Piegan group become dominant.

Piegan group: The name Piegan group was originally applied by Fenton and Fenton (1937b, pp. 1890-1900) in Glacier National Park to the predominantly calcareous and argillaceous sequence of beds which lie between the Ravalli and Missoula Groups. This sequence of beds is generally known as the Siyeh, Spokane, and Sheppard formations, in ascending order. Piegan Mountain in Glacier National Park is the type locality. Ross (1959a, Table 1) recently proposed that the Piegan group should be restricted to the Siyeh limestone in Glacier National Park, and to the Newland limestone from the vicinity of Missoula eastward to the Little Belt Mountains.

Johns (1959, p. 11) introduced the term Piegan group in the Libby quadrangle for a calcareous assemblage of rocks which are generally called the Wallace formation, and continued the correlation into the other quadrangles of the Kootenai-Flathead project area (Johns, 1960, 1961).

In the NW Pleasant Valley quadrangle, rocks of the Piegan group are exposed in the northeast and east, where they occupy the trough of the Ingalls syncline (Plate 1). Approximately 7,000 feet of lower and middle Piegan strata are exposed in the quadrangle; an unknown thickness of the upper part of the Piegan has been removed by erosion. In the North Thompson Lakes quadrangle just to the west of the map area, the group is approximately 14,000 feet thick (Johns, 1960, p. 11). If the Piegan group in the map area was once of a comparable thickness, then approximately 7,000 feet have been eroded.

The lower Piegan unit is approximately 3,500 feet thick in the map area, and consists dominantly of greenish-gray to gray, laminated to thin-bedded argillites and calcareous argillites, which are frequently silty. Some purplish-gray calcareous argillites and impure limestones occur in the lowermost part. Sun cracks were noted in some of the beds.

In thin section, the rock appears to be a dominantly argillaceous matt containing abundant sericite and scattered patches of coarser grained calcite and dolomite. Thin laminae of fine-grained, recrystallized quartz occur intermittently, and fine-grained particles of quartz are scattered throughout the argillaceous matt. Chlorite, occurring as minute flakes, is present in the sections in minor amounts.

Near the top of this basal unit, southwest of Ingalls Mountain, several siliceous, oval-shaped, elongate masses approximately one and one-half inches in diameter and up to eight inches long occur parallel to the bedding. In thin section, the ovoids are composed of a mosaic of interlocking, strongly recrystallized quartz grains up to 0.1 mm. in diameter. Laminae of fine-grained quartz and argillaceous material are draped around the ovoids and some faint laminae pass through them. Veinlets of quartz and calcite and some scattered patches of calcite are present in the ovoids. These siliceous ovoids are indefinite in origin.

Near the base of this lower unit, the strata weather pale greenish-gray and contain occasional masses and cubes of pyrite. Toward the top of this unit, pyrite becomes more abundant, and the strata weather to pale shades of brown.

This lower unit grades upward into middle Piegan strata, of which the lower 3,500 feet have escaped erosion. The middle Piegan consists dominantly of bluish-gray to dark-gray, and light to greenish-gray, silty, calcareous argillites, dolomites, and impure limestones. Pyrite is abundant, commonly occurring in cubes up to one-half inch across. The strata are laminated to thick-bedded, and generally weather to blocky or massive units; however, the units sometimes have a platy appearance. Outcrop surfaces typically weather to shades of brown, yellow, and orange, and sometimes exhibit irregular bedding. Interbedded in the middle unit are some beds of light greenish-gray to white, very thick-bedded, siliceous dolomite and limestone, which characteristically weather to a reddish-brown color that penetrates one-quarter to one inch into outcrops.

In thin section, the middle Piegan consists of fine-grained carbonate in an argillaceous matrix. Considerably more carbonate (up to 50 percent of the rock) is present than in sections from the lower Piegan. In places, fine-grained patches of recrystallized quartz are present. Sericite is present in varying amounts, and minor amounts of chlorite occur as minute flakes. This mineralogic assemblage indicates that the Piegan strata in the map area have been metamorphosed to a quartz-albite-muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1960, pp. 534-536).

Near the lower part of this middle unit, and possibly extending into the upper part of the lower Piegan unit, the strata frequently exhibit a characteristic pitted weathered surface. These pits are aligned parallel to bedding and are the result of the differential weathering out of oval-shaped nodules of calcite (Fig. 10). The calcite nodules range up to two or three inches in diameter, and are light-gray to bluish-gray in hand specimens. The nodules are generally separated, but in some places they are connected by pinching and swelling along the bedding. Argillaceous laminae are draped around the nodules, and some faint laminae pass through them parallel to bedding. Minute fractures occasionally pass through the nodules, but do not penetrate into the surrounding argillaceous material.

Figure 10. Exposure of middle Piegan strata, along Dunsire Creek road, probably low in the middle Piegan. Note fresh and weathered surfaces, the pitted weathering, and oval-shaped calcite nodules just above the pick.

Some of the calcite masses occur as short, rod-shaped bodies which are perpendicular to the bedding. These rods wedge-out downward, and appear to depress the underlying argillaceous material. The top of the rods appear to have been surfaces of deposition, i.e., argillaceous material was deposited over them. In a few instances, small fingers of calcite radiate upward from apparent growth centers. Pyrite, in masses and cubes, is abundant in nearly all the calcite masses.

The above relationships suggest that at least some of these calcite masses may be organic in origin, possibly the result of lime-forming algae. The algae, some of which may have been in the form of matts, could have provided reducing conditions under which the pyrite was formed.

Similar features have been described as "segregation structures" in the Piegan group in widespread areas by several workers, including Daly (1912), Fenton and Fenton (1937b), and Sheldon (1961). In the map area, it could not be determined whether all the calcite masses originally formed in their present shapes. Some of the calcite may have been segregated into the nodules by squeezing of relatively plastic algal matts, possibly during broad-scale warping and mild uplifting during Beltian time. Other possible mechanisms which may have resulted in segregation of the calcite are variations in loading of the overlying sediments, and uneven compaction of the underlying sediments.

Higher in the middle Piegan, the strata exhibit a conspicuous weathering pattern known as "molar-tooth structure" (Daly, 1912, p. 74), because the pattern resembles the markings in the molar tooth of an elephant. In one of the sections from the middle Piegan, black carbonaceous material, which may be algal in origin, occurs as thin wavy laminae roughly paralleling the bedding. Although stromatolites are common in the Piegan group in other areas, no definite examples were found in the map area.

Erosion has removed higher beds of the middle Piegan and the upper part of the group in the map area.

QUATERNARY DEPOSITS

In the map area, sediments younger than the Belt series consist of Quaternary deposits and include Pleistocene glacial drift and Recent alluvium. These deposits were grouped together as Quaternary glacial deposits (Plate 1) in the reconnaissance mapping, and were mapped only where the thickness exceeds an estimated 40 to 50 feet.

Pleistocene glacial drift is a conspicuous feature in most of the major drainages of the NW Pleasant Valley quadrangle, covering most of the valley floors and extending well up on the mountain slopes. The drift includes glacial till, outwash, and lacustrine silt.

Till and outwash material comprise most of the glacial drift in the area and consist of a heterogeneous mixture of clayey, silty, and sandy material, containing gravel, cobbles, and boulders of various sizes. Some of the rock fragments are striated, and most appear to be Belt-derived, although a few erratic igneous cobbles are present in some of the debris.

Exposures of buff-colored, horizontally stratified, lacustrine silt occur along upper Hand Creek (Fig. 4) and lower Little Wolf Creek. In places, the silts appear to overlie glacial till, gravel, or boulder material.

Recent alluvium for the most part is apparently derived from reworked glacial debris, and consists mainly of silt, sand, and gravel found in and along the stream channels.

STRUCTURAL GEOLOGY

STRUCTURAL SETTING

The eastern edge of the Rocky Mountains in northwest Montana is characterized by a zone of west-dipping imbricate thrust faults. A major thrust fault, the Lewis overthrust, is the dominant structural feature in this zone. West of the Lewis overthrust a broad northwest-trending syncline occurs in the Beltian strata along the Continental Divide in Glacier National Park. The west flank of this syncline is characterized by a series of west-dipping normal faults which probably postdate thrusting (Woodward, 1959).

A topographic trough known as the Rocky Mountain Trench occurs along the southwest margin of the area discussed above (Fig. 1). The origin of this prominent feature, and whether or not it serves as a structural boundary is controversial. At the International Boundary Daly (1912) suggested that the trench is a graben, or also possibly a fault zone with a master normal fault. In the Brisco-Dogtooth area of Canada, Evans (1932) suggested it is a zone of opposed thrust faults, producing an intensely sheared zone which was easily eroded.

West of the Rocky Mountain Trench, in the area of the Flathead Valley in the vicinity of Kalispell, Montana, the Beltian strata are characterized by north to northwest-trending folds, which include both broad and relatively tight symmetrical and asymmetrical structures. Longitudinal faults and transverse faults commonly cut the folds. Longitudinal faults, which include high-angle thrusts and normal faults, have the largest displacements and greatest lengths. The Moyie-Lenia thrust, located approximately 50 miles west of the map area, has been traced for 118 miles in Montana, Idaho, and British Columbia, and has stratigraphic throws of 15,000 to 45,000 feet (Kirkham, 1930, pp. 367-373). Transverse faults, which include northeast and east-striking groups, commonly displace northwest-trending structures (Johns, 1959, 1960, 1961).

FOLDS

In the NW Pleasant Valley quadrangle, folding follows the general northwest structural trend of the region. Three major, persistent folds and several smaller folds occur in the area (Plate 1).

In the west, a slightly asymmetrical syncline trends generally in a northwest direction through the map area. This fold, named the Wolf Creek syncline for its intersection with Wolf Creek in the area, continues into the SW Pleasant Valley quadrangle (Johns, 1962), and is roughly 25 miles long. Dips on the east flank average 10° - 20°, and dips on the west flank average slightly higher, on the order of 20°. Rocks of the Ravalli group occur in the trough of this fold, except where streams have cut down and exposed the underlying Prichard formation; Prichard rocks crop out on both limbs. The west limb of this syncline is the common east limb of a broad, relatively symmetrical anticline, known as the Wolf Creek anticline, which occurs just west of the map area (Johns, 1960).

Wolf Creek broken [illegible]
[illegible] making Elk Mtn anticline

In the northern part of the quadrangle, the east flank of the Wolf Creek syncline is the common west flank of the Elk Mountain anticline, a major asymmetrical fold named for its proximity to Elk Mountain (Plate 1). The fold continues into the SE Pleasant Valley quadrangle (Johns, 1962), and also plunges gently northwestward out of the map area and into the unmapped SW Stryker quadrangle. This fold has been traced for approximately 30 miles, and trends generally N 25°W in the map area. The axial plane of this anticline dips steeply to the southwest, and dips on the east flank range from 30° - 90°, with local overturning toward the northeast. In the central part of the quadrangle the axial trace of this fold is cut by the sinistral strike-slip Elk Divide fault.

In the southern part of the quadrangle, four folds occur between the Wolf Creek syncline and the Elk Mountain anticline. An anticline and a syncline, which are symmetrical and generally parallel to each other, occur just east of Horse Hill (Plate 1). These two folds are approximately seven miles long, and change from a northwest trend in their southern part to a northeast trend in their northern part. Both folds plunge gently to the south, and in a northward direction it is probable that they terminate against the Elk Divide Fault.

An anticline and a syncline pass into the map area from the south in the vicinity of Grubb Mountain, and trend in a general northwest direction for approximately six miles to where they die out in the vicinity of Mount Connor. These two folds are relatively symmetrical, and plunge gently northward in the quadrangle.

The east flank of the Elk Mountain anticline is the common west flank of the Ingalls syncline which occurs in the eastern part of the quadrangle near Ingalls Mountain; rocks of the Piegan group occupy the trough of this fold in the area of study. The syncline trends approximately N 25°W, and plunges gently northward through the quadrangle to the unmapped SW Stryker quadrangle. Dips on the east flank average 10° - 20°. The fold continues into the NE and SE Pleasant Valley quadrangles (Johns, 1962), and has been traced for approximately twenty miles. The axial trace of the fold has been cut by the Elk Divide fault in the central part of the quadrangle.

In the northeast part of the map area, a series of relatively symmetrical folds occurs in rocks of the Piegan group. The easternmost fold, an anticline, passes into the area from the NE Pleasant Valley quadrangle (Johns, 1962). This fold has been traced for approximately seven miles to where it plunges gently northward into the unmapped SW Stryker quadrangle. The other folds, which consist of two anticlines and two synclines, are two to five miles long in the NW Pleasant Valley quadrangle. These folds plunge gently northward and their southern terminations are in the vicinity of Fox Mountain.

FAULTS

Longitudinal faults (thrusts): A major longitudinal fault has been traced from the southeast corner to the northwest corner of the map area, and is interpreted as a high-angle thrust fault dipping to the west. This structure crosses Elk Divide at Brush Pass (Plate 1) in the quadrangle, and is named the Brush Pass thrust. The fault has been mapped in a southeast direction in the SE Pleasant Valley quadrangle where it terminates just east of Little Bitterroot Lake by curving to the east and northeast and splitting into several segments (Johns, 1962). In the northwest corner of the map area, the fault apparently continues into the unmapped SW Stryker quadrangle. It is probably continuous with the Gut Creek-Pinkham Creek fault, a high-angle thrust fault mapped in the Ural quadrangle (Johns, 1961, p. 29), and may have a total length of approximately 70 miles. In the Ural quadrangle, stratigraphic throw on the Gut

Creek-Pinkham Creek fault is in excess of 7,000 feet as rocks of the Prichard formation on the west have been thrust into contact with rocks of the Piegan group (Johns, 1961, p. 29).

In the map area, the fault generally follows the east flank of the Elk Mountain anticline, and trends approximately N 25°W. On the basis of the configuration of the fault trace across topography, and the asymmetry of the associated folding, the fault is believed to dip west at a high angle. Just northwest of Elk Mountain, a disturbed zone approximately fifteen feet wide occurs on the fault trace. This zone, marked by a prominent notch across the ridgeline, dips to the west at approximately 70° - 75°, and is characterized by outcrops of highly fractured and contorted rocks. Rocks of the lower Ravalli on the west side of this zone have been thrust up into contact with rocks of the middle Ravalli on the east side of this zone. The stratigraphic throw and dip-slip at this location are probably on the order of 3,000 feet. To the southeast, in the vicinity of Sylvia Lake, the stratigraphic throw on the fault is approximately 6,000 feet, as rocks of the Prichard formatiom were thrust into contact with rocks of the Ravalii group located just below the calcareous unit of the upper Ravalli.

In the eastern part of the quadrangle, a longitudinal fault named the Dunsire thrust occurs mainly in rocks of the Piegan group. The fault trace is approximately N 25°W in the area, and the fault zone is apparently marked by Dunsire Creek, from which the structure takes its name. A high-angle thrust fault mapped by Johns (1961) in the Ural quadrangle may be the northwest continuation of this fault. Southeastward the Dunsire thrust continues into the SE Pleasant Valley quadrangle

(Johns, 1962) and dies out just west of Ashley Lake. The total length of the fault may be approximately 45 miles. Through most of the map area, lower Piegan rocks west of the fault have been thrust up into contact with rocks of the middle Piegan on the east. On a ridgeline approximately one and one-half miles northeast of Sylvia Lake, greenish-gray calcareous argillites of the lower Piegan unit on the west side of the fault were thrust up into contact with the white siliceous dolomite and bluish-gray impure limestone beds of the middle Piegan unit on the east. The stratigraphic throw and dip-slip on this fault are apparently on the order of 2,500 feet.

Transverse faults: A major transverse fault occurs in the central part of the quadrangle, and strikes generally N 85°W. This structure, named the Elk Divide fault for its intersection with that topographic feature in the map area, is apparently the continuation of an east-trending fault mapped in the NE Pleasant Valley quadrangle (Johns, 1962), and may have an approximate length of fifteen miles. The fault apparently dies out to the west in the vicinity of Wolf Creek. On the basis of the configuration of the fault trace and the attitude of associated shears, the fault is believed to be near the vertical. Sedimentary contacts, longitudinal fault traces, and fold axial traces have been displaced left-laterally along the strike of the fault. The fault has a left-lateral separation of approximately one-half mile where it cuts the Elk Mountain anticline, and approximately one-quarter mile further to the east in the vicinity of the Ravalli-Piegan contact and the Ingalls syncline Plate 1). Near Wolf Creek to the west, the axial traces of two southward plunging folds appear to end abruptly at the fault trace, suggesting that the fault extends a short distance west of Wolf Creek. However, there is not sufficient control to determine whether the Prichard-Ravalli contact is displaced.

The left-lateral separation of planar structures with different attitudes which intersect the fault strike, plus associated drag folding where the fault intersects Elk Divide (Plate 1), indicate a sinistral strike-slip fault.

South of the fault, the strata are more intensely folded than those on the north side. In the central part of the quadrangle, dips on the east limb of the Elk Mountain anticline range from 32° - 51° just north of the fault, except where drag along the fault has produced modifications. Just south of the fault, dips range from 65° - 90°, with local overturning toward the northeast. South of the fault, the stratigraphic throws on the thrust faults are greater than on the north side. The more intense folding and thrusting south of the fault indicate that folding and thrusting continued after the fault was initiated. The two folds which end abruptly at the fault trace near Wolf Creek are probably a result of the greater compression that took place south of the fault.

A system of transverse faults, which are believed to post-date the thrusts and the Elk Divide fault, is present in the map area. These faults appear to be high-angle, dominantly dip-slip faults, and they have east and northeast trends. The faults commonly cut the traces of northwest-trending structures, and show significant lateral separations of structures which have dips somewhat less than 90°. Johns (1959, 1960, 1961) has mapped similar northeast and east-trending faults which displace northwest-trending structures.

A northeast-trending transverse fault is present in the southern part of the quadrangle just east of Sanders Mountain. Toward the northeast this fault appears to die out at the Brush Pass Thrust, and toward the southwest it terminates in the SW Pleasant Valley quadrangle. This fault is approximately seven miles long, and its trace across topography indicates a high angle of dip. The fault trace cuts across the axial traces of a symmetrical anticline and syncline, but does not appear to displace them laterally. In places, rocks of the Prichard formation on the northwest side of the fault have been brought into contact with the Ravalli group on the southeast side. Movement on this fault was probably dominantly dip-slip, resulting in a stratigraphic throw of roughly 1,000 feet. The northwest side is upthrown relative to the southeast side.

An east-trending fault approaches the northeast fault just north of Grubb Mountain, and continues eastward into the NE Pleasant Valley quadrangle (Johns, 1962). This structure has been traced for roughly nine miles, and appears to be a high-angle fault with dominant dip-slip movement. The south side has been upthrown relative to the north side, roughly 500 to 1000 feet. The age relationship between the northeast and east-trending fault could not be determined in the area. It is possible that they may be contemporaneous.

Southeast of Sylvia Lake, an east-trending fault apparently displaces the Dunsire thrust and the Piegan-Ravalli contact. The west-dipping Dunsire thrust shows a right-lateral separation, and the east-dipping Piegan-Ravalli contact shows a left-lateral separation along the fault strike (Plate 1). The movement on this fault was apparently dominantly dip-slip and of considerable magnitude, possibly on the order of 2,000 feet judging from the amount of lateral separation shown; the south side is upthrown relative to the north side. The fault apparently dies out to the west at the Brush Pass thrust, and its trace is about two miles long.

In the western part of the map area, an east-trending fault is present just northeast of Horse Hill. The fault trace is approximately three miles long, and is located on an east-trending ridge for part of its length; the trace configuration across topography indicates a high-angle of dip. Two small sloughs, which are spring-fed, occur on the fault trace. Greenish-gray quartzitic argillites of the lower Ravalli on the south side of the fault are in contact with blocky to massive, light-gray quartzite of the middle Ravalli on the north side of the fault. This indicates that the south side is upthrown relative to the north side, probably on the order of 1,000 feet. Movement on the fault was probably dominantly dip-slip, because the fault trace cuts across the axial traces of a symmetrical anticline and syncline, but does not displace them laterally.

In the northeast part of the quadrangle, just south of Fox Mountain, an east-trending fault may occur for approximately two miles in the area; this structure is indicated by a distinct furrow on aerial photographs. The fault is probably a continuation of an east-striking fault mapped for approximately seven miles in the NE Pleasant Valley quadrangle (Johns, 1962), which is upthrown on the south side relative to the north side.

In the northwest part of the quadrangle, an east-trending fault appears to pass into the area from the west and continues for about one mile eastward. This fault is probably the eastward extension of the

Cripple Horse Creek fault mapped in the NE Thompson Lakes quadrangle (Johns, 1960). A spring-fed slough occurs on the fault trace where it transects the crest of a ridge in the quadrangle

In the northwest corner of the map area, a distinct, northeast-trending lineament produced by an alignment of springs and seeps is evident on aerial photographs. An upper branch of Wolf Creek issues from this lineament, and flows over a waterfall about 20 feet high into a steep-sided gorge. Signs of shearing were noted in the northern part of the gorge, strongly suggestive of faulting. The trace of the fault trends approximately N 30°E, and its configuration across topography indicates a high angle of dip. The fault cuts across the axial trace of the Elk Mountain anticline, but apparently does not displace it laterally. Movement on the fault was probably dominantly dip-slip and on the order of 200 feet or less, as it apparently has not resulted in displacement of the Prichard-Ravalli contact.

On aerial photographs, a distinct, east-trending furrow intersects the trace of the northeast-trending fault in the northwest corner of the quadrangle. Two branches of upper Wolf Creek originate in this furrow, suggesting that a fault is present. The fault trace is approximately three miles long, and its configuration across topography indicates a high angle of dip. The axial trace of the Elk Mountain anticline is cut by the fault trace, but does not appear to be displaced laterally. Movement was probably dip-slip, and most likely less than 200 feet. At the intersection of the east and northeast-trending faults, one fault does not appear to displace the other, indicating that they may be contemporaneous. However, this relationship is not conclusive.

FRACTURE CLEAVAGE

A well-developed fracture cleavage is present in strata along the length of the steep-dipping east flank of the Elk Mountain anticline in the map area. The cleavage was not found outside the steep flank of this anticline, and is localized on the steep limb apparently as a result of the more intense shearing of beds past one another which occurred there during the folding. The cleavage strikes generally north-northwest and dips to the west at angles ranging from 45° - 65°. This orientation closely approaches that of the axial planes of the Elk Mountain anticline and the Ingalls syncline, in the quadrangle, and also that of the high-angle thrust faults.

The cleavage in the area is characteristically present in relatively incompetent argillaceous beds located between more competent quartzitic units. A typical example of the cleavage is that which occurs in the calcareous argillite unit of the upper Ravalli group (Fig. 9). This relatively incompetent unit is bounded above and below by thick-bedded, competent quartzites of the Ravalli group which do not exhibit the cleavage.

JOINTS

Throughout the map area, the Beltian strata commonly exhibit pronounced jointing. Although a detailed joint study was not possible due to the reconnaissance nature of the mapping, any pronounced joints which were encountered during the mapping were recorded. A total of 40 joint readings were taken, and the poles were plotted on the lower hemisphere of an equal area net (Fig. 11).

As Figure 11 shows, the most prominent joint set strikes about N 85°W, and is near the vertical. These joints occur in all lithologies in the map area, and are typified by those shown in Fig. 5. Quartz veins up to fourteen inches wide commonly occur along these west-northwest trending joints.

A second, northeast-trending, steeply-dipping joint set is also evident from Figure 11. Joints of the northeast-trending set are not as abundant as the west-northwest set, but where encountered they are well-developed. This set strikes generally about N 30°E, and is near the vertical.

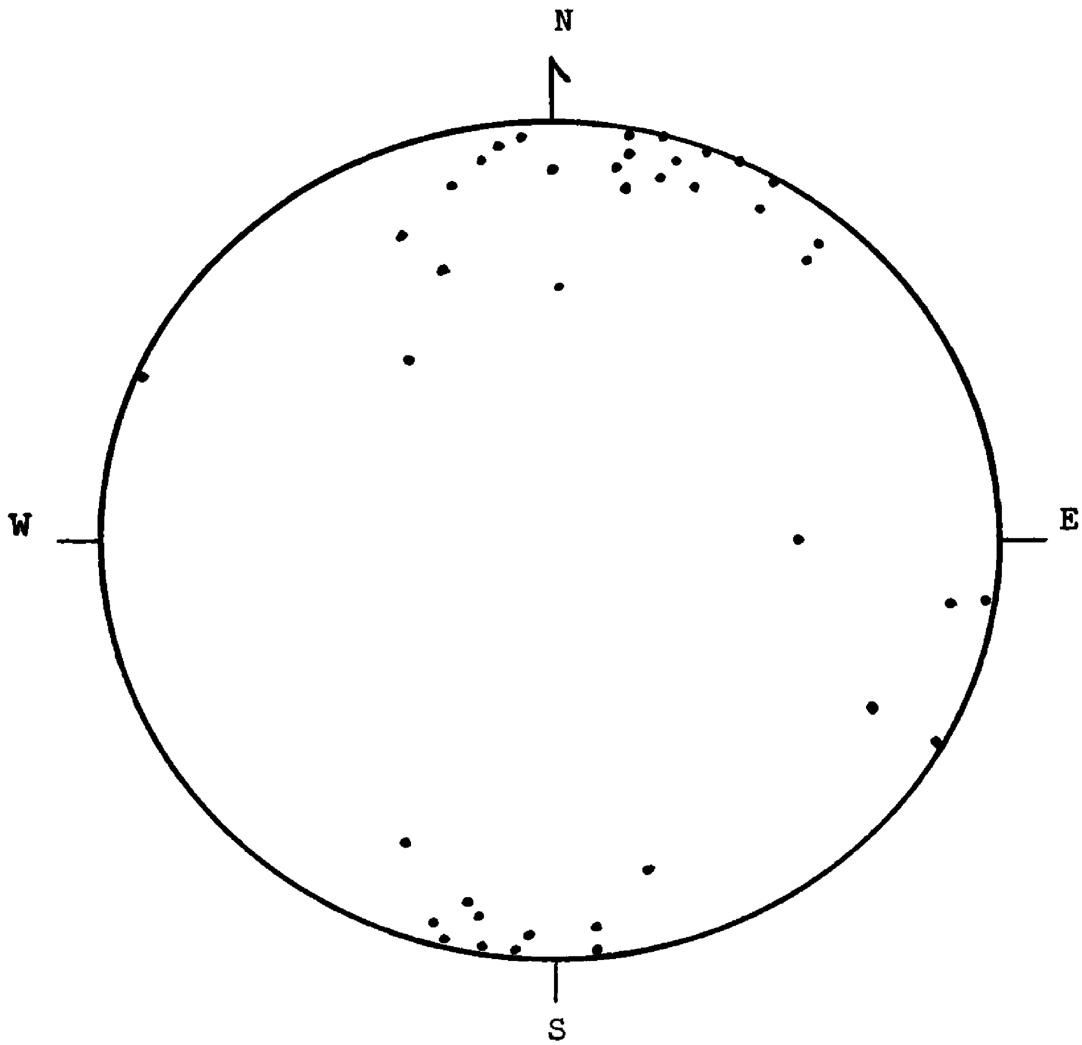

Figure 11. Stereographic plot, poles of 40 joints, lower hemisphere.

STRUCTURAL RELATIONSHIPS

In the NW Pleasant Valley quadrangle, the major folds trend in a north-northwest direction, closely following the general structural trend of the region, and the axial planes of the major folds dip steeply to the southwest. Two associated high-angle thrust faults also dip to the southwest, and generally strike parallel to fold axial traces. The general strike of the folds and the thrust faults is approximately N 25°W in the quadrangle, indicating that the principal compressive stress which produced these structures had a direction of approximately N 65°E.

It is interesting to note that the Elk Divide fault in the central part of the area, with a general strike of N 85°W, makes an angle of approximately 30° with the major stress direction, a characteristic of diagonal strike-slip faults. The sinistral sense of strike-slip movement on the Elk Divide fault is also in accordance with this stress pattern in the map area. This relationship is not uncommon. Such strike-slip faults are frequently associated with folding and thrusting, as, for example, the Valganna fault of the Lombardy Alps (De Sitter, 1959, p. 166), and the strike-slip faults in the Jura Mountains of northern Switzerland and in southwestern Wales (Billings, 1954, pp. 212-214).

In the map area, the folding, thrusting, and strike-slip movement appear to have been produced by the same general stresses, which probably were the result of horizontal compressive forces directed east-northeast. It is also noteworthy that the two joint sets (Fig. 11) are not perpendicular to the fold axes which would be expected if they were extension joints, but instead form an acute angle opening to the west-southwest.

This conjugate system is typical of shear fractures. According to Hartmann's Law, the acute angles of conjugate shear sets point the direction of maximum compression, and in this case that direction is east-northeast to west-southwest, the same principal stress direction established for the folding, thrusting, and strike-slip faulting. The fact that quartz veins commonly occur along the joints could be explained by elastic release of the stress-field, which may have opened up the joints permitting them to be filled with vein material.

Later transverse faults in the map area are interpreted as normal faults, and may be the result of relaxation of strains set up during the folding and thrusting. It is also possible that they may belong to a later period of faulting. The east and northeast trends of these faults closely approach those of the two joint sets in the area (Fig. 11), suggesting there may be a relationship between the jointing and faulting. These later transverse faults may have followed the directions of weakness established by the jointing.

AGE OF FOLDING AND FAULTING

In the NW Pleasant Valley quadrangle, definite evidence for the age of the folding and faulting is lacking, and the age must be based on regional geologic interpretations. From several lines of evidence, it is known that some regional warping of the Beltian sediments occurred during late Precambrian or early Paleozoic time. After deposition of the Beltian strata ceased and before deposition of the middle Cambrian Flathead sandstone, some diastrophism took place in western Montana, tilting the strata as much as 30 degrees in the Phillipsburg area, and elevating the beds at least 20,000 feet on the eastern side of the Big Belt Mountains (Deiss, 1935, p. 106). Between the northern boundary of the Phillipsburg quadrangle and the Clark Fork River in Montana, Maxwell (1959) utilized point diagrams of poles of bedding for Paleozoic rocks and Beltian rocks to show that the Belt sediments were strongly tilted, warped, and probably faulted before Cambrian sediments were deposited. However, the effect that this deformation had on the Belt sediments in the map area located some 150 miles to the northwest is conjectural.

Johns (1960, p. 14) mapped folded and faulted Cambrian rocks in the Thompson Lakes quadrangle to the west. In the NE Ural quadrangle to the northwest, a faulted block of Devonian limestone was mapped (Johns, 1961, p. 29), indicating that some deformation is at least post-Devonian.

The Moyie-Lenia fault to the west of the map area cuts a cupola of what is assumed to be an outlier of the Idaho batholith (Kirkham, 1930, p. 373). Age determinationsby the lead-alpha activity ratios on zircon and other mineral constituents on rocks from the Idaho batholith average 108 million years, placing the age of the batholith in the middle Cretaceous (Larsen, et al., 1958).

The Lewis overthrust has been dated as Eocene (MacKenzie, 1922, p. 115), and Ross (1959b, p. 95) concurs that the thrust took place in the latter part of the Paleocene or during the Eocene epoch. In the central part of the Sawtooth Range, located south of Glacier National Park, the deformation which produced the folding, thrusting, and normal faulting probably took place during the Laramide Revolution (Deiss, 1943b, pp. 1162-1163).

In consideration of the regional structural pattern, it is probable that at least some of the deformation in the map area is related to the Laramide orogeny.

ECONOMIC GEOLOGY

Evidence for any commercial mineralization is lacking in the NW Pleasant Valley quadrangle. Only one mine was found in the area; it is located just northwest of the lookout on Horse Hill at the western edge of sec. 30, T. 30 N., R. 26 W. The history of the mine could not be determined. A fourteen-inch quartz vein has been worked by a 50-foot adit trending S 70°E along the vein; a winze, now filled with water, occurs at the end of the adit. Random samples were taken from the vein and mine tailings, but analysis indicated they were relatively barren of base and precious metals. Several other quartz veins in the area were sampled, but these also proved to be relatively barren; one six-inch quartz vein located in sec. 33, T. 30 N., T. 26 W. contained one ounce per ton of silver and a trace of gold. All the veins sampled contained traces of gold.

Nonmetallic deposits examined in the map area include clay, limestone, and quartzite, but none appear to be of commercial value. A sample from one of the white quartzite beds of the upper Ravalli group contained 86.0% silica, however this is probably not of metallurgical grade.

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APPENDIX

THIN SECTION DATA

Section no.	Description	Location
1	Upper Prichard formation: light and dark-gray laminated argillite, biotite porphyroblasts.	T 30 N, R 27 W. sec 12, SW $\frac{1}{4}$
2	Upper Prichard formation: light to dark-gray thinly laminated argillite, some locally calcareous beds.	T 30 N, R 26 W, sec 11, SE $\frac{1}{4}$
3	Upper Prichard formation: light gray argillite with thin medium gray and white laminae, biotite porphyroblasts conc. in laminae.	T 30 N, R 25 W, sec 19, SE $\frac{1}{4}$.
4	Calcareous unit upper Prichard formation: Medium-gray calcareous argillite and l s., thin white laminae, abundant porphyroblasts of biotite .	T 31 N, R 26 W, sec 8, NE $\frac{1}{4}$.
100	Middle Ravalli group: Light-gray quartzite, thin to thick-bedded, magnetite octahedra.	T 29 N, R 25 W, sec 3, N$\frac{1}{4}$.
101	Upper Ravalli group: Light to medium-gray quartzite and subordinate argillite, locally calcareous.	T 30 N, R 25 W, sec 18, NW $\frac{1}{4}$.
102	Upper Ravalli group: Light-gray, purple-laminated quartzite, thin to thick-bedded; clay chips in interbedded argillite.	T 30 N, R 25 W, sec 7, NW $\frac{1}{4}$.
103	Uppermost Ravalli group: Very light-gray to white quartzite, thin purple laminae, cross-bedded.	T 30 N, R 25 W, sec 7, NW $\frac{1}{4}$.

200	Lower unit Piegan group: Greenish-gray calcareous argillite, thin-bedded, local siliceous laminae.	T 30 N, R 25 W, sec 6, NE $\frac{1}{4}$.
201	Lower unit Piegan group: Thin greenish-gray argillaceous and siliceous laminae surrounding siliceous ovoid, locally calc.	T 30 N, R 25 W, sec 27, NE $\frac{1}{4}$.
202	Middle unit Piegan group: Dark-blue-gray silty limestone and calcareous argillite, light-gray laminations.	T 31 N, R 26 W, sec 1, NW $\frac{1}{4}$.
204	Middle unit Piegan group: Light-gray to light greenish-gray 1 s. and calcareous argillite, very thin-bedded to laminated.	T 30 W, R 25 W, sec 6, NE $\frac{1}{4}$.